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Chapter 5

SWEET POTATO PUREES AND DEHYDRATED POWDERS FOR FUNCTIONAL FOOD INGREDIENTS#

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ABSTRACT

Processing technologies have been developed in various parts of the world to convert sweet potatoes into purees and dehydrated forms that can be used as functional ingredients in numerous food products. This chapter reviews the processing operations involved in these technologies and their effects on quality, storability, nutritional values and rheological properties of sweet potato purees and powders/flours. For purees, the processing steps include peeling, cutting/grinding, and pre-cooking/finish-cooking with temperature-time program suitable for starch conversion by endogenous amylolytic enzymes to obtain the products with targeted maltose levels and viscosities. The purees can be subsequently preserved by refrigerated and frozen storage, canning, or aseptic packaging. However, poor product quality due to excessive thermal treatments in canning, high cost of investment associated with frozen products and limited package sizes of these preserved forms are the main hurdles for widespread applications of sweet potato purees in the food industry. These problems can be overcome by a new process using a continuous flow microwave system for rapid sterilization and aseptic packaging to produce shelf-stable purees with consistently high quality. Sweet potato purees can be further processed into drum- or spray-dried powders. In many countries, solar drying and

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mechanical drying in cabinets and tunnels are common in producing sweet potato dried chips which are pulverized into flours. Extrusion technology and chemical treatments are also applied to produce sweet potato powders for specific functionality. With high levels of carbohydrates, ß-carotene (orange-fleshed varieties) and anthocyanins (purple-fleshed varieties), sweet potato purees and dehydrated forms can be used as functional ingredients to impart desired textural properties and phytonutrient content in processed food products.

ABBREVIATIONS

CPV	cold paste viscosity;
DPPH	2, 2-diphenyl-1-picrylhydrazyl;
DS	degree of substitution;
DSC	Differential Scanning Colorimeter;
DRI	dietary reference intake;
GI	glycemic index;
HPV	hot paste viscosity;
NASA	National Aeronautics and Space Administration;
ORAC	oxygen radical absorbance capacity;
PER	protein efficiency ratio;
SAPP	sodium acid pyrophosphate;
PV	peak viscosity;
RTE	ready- to- eat.

INTRODUCTION

Sweet potato ranks the seventh most important food crop in the world and fourth in tropical countries (FAOSTAT, 2004). In comparison to other major staple food crops, sweet potato has the following positive attributes: wide production geography, adaptability to marginal condition, short production cycle, high nutritional value and sensory versatility in terms of flesh colors, taste and texture. Depending on the flesh color, sweet potatoes are rich in ß -carotene, anthocyanins, total phenolics, dietary fiber, ascorbic acid, folic acid and minerals (Woolfe, 1992; Bovell-Benjamin, 2007; ILSI, 2008). Therefore, sweet potato has an exciting potential for contributing to the human diets around the world. However, the world trends in sweet potato production and consumption do not support the position of this highly nutritious vegetable. In the United States, the annual per capita consumption of sweet potato was declined in the last decades from 12 kg to 2 kg while the potato consumption was increased to over 60 kg (USDA, 2002). The situation can be attributable to the inadequacy in sweet potato manufacturing technologies for processed products, and the increased demand of consumers for convenient products. Research efforts have demonstrated that sweet potatoes can be made into liquid and semi-solid food products such as beverages, soups, baby foods, ice cream, baked products, restructured fries, breakfast cereals, and various snack and dessert items (Collins and Walter, 1992; Dansby and Bovell-Benjamin, 2003a; Truong, 1992; Truong *et al.,* 1995; Walter *et al.,* 2001, Woolfe, 1992). Puree and dehydrated forms processed from sweet potatoes are the main ingredients that provide the functionality required in these processed products. For the food processing industry, the unavailability of puree and dehydrated forms for diverse functionalities is a limiting factor in the utilization of sweet potatoes in processed foods. Several excellent reviews dealing with processing and quality aspects of sweet potato purees, flakes and powders have been published over the past 20 years (Collins and Walter, 1992; Kays, 1985; van Hal, 2000; Woolfe, 1992). This chapter updates these reviews with recent developments in processing technologies to convert sweet potatoes into purees and powders that can be readily used by the food industry as functional ingredients in processed foods.

SWEET POTATO PUREES AS FUNCTIONAL INGREDIENTS

The use of sweet potatoes in the food industry often involves processing of the roots into purees that can be subsequently frozen, canned or packaged in aseptic conditions to produce shelf-stable products for year-round availability of the produce. For pureeing, roots of all sizes and shapes can be processed to make acceptable puree and therefore, the entire harvested crop is utilized including the 30-40% off-grade from the fresh root markets. Purees from the orange-fleshed sweet potatoes have been commercially produced in cans or in frozen form in the U. S (Kays, 1985; Walter and Schwartz, 1993). In Japan, both white- or orange-fleshed cultivars are utilized for processing into paste for incorporation into bread and ice cream (Woolfe, 1992). The challenges in puree processing industry are: (1) the difficulty in adjusting the process to account for differences in cultivar types; root handling, curing, and storage; and other parameters in order to produce consistent, and high puree quality, and (2) the preservation technology that could produce shelf-stable product for convenient incorporation in processed foods.

A wide range of dry matter (18 – 45%) and starch content (8 – 33.5%, fresh weight basis) exists among sweet potato genotypes (Brabet *et al.*, 1998; Yencho *et al.*, 2008) which have significant impact on processing operations and quality of the purees. Post-harvest handling of sweet potatoes can have significant effect on the purees made from them. Metabolic changes may affect the appearance, texture, flavor and nutrient composition of the purees. Curing by subjecting sweet potatoes to 30°C, 85% to 90% relative humidity for 4-7 days as commercially practiced in the U. S. can result in an increase in sugars, and a decrease in starch and alcohol-insoluble solids (Boyette *et al.*, 1997). Several investigators reported that changes in carbohydrate components and enzyme activities (α-amylase, β-amylase, invertases and sucrose synthase) during curing and storage of sweet potatoes are genotype dependent (Huang *et al.*, 1999; Picha, 1986; Takahata *et al.*, 1995; Walter, 1987).

In general, amylase activities in sweet potato roots are increased by curing and storage especially during the first few months, then remain fairly constant or decrease to the levels at harvest (Shen and Sterling, 1981; Walter *et al.*, 1976; Zhang *et al.*, 2002). On the other hand, there are genotypes, e.g. Kyukei 123, with relatively constant levels of starch, sucrose and amylase activity throughout storage (Takahata *et al.*, 1995). The activities of α-amylase and β-amylase in raw sweet potatoes affect the processing operations and quality of the purees. When the sweet potatoes are heated to starch gelatinization temperature (60 to 78°C), α-amylase rapidly degrades the starch to lower molecular weight dextrins which are concurrently hydrolyzed into maltose by β-amylase. The degree of starch degradation and maltose formation is dependent on the activities of amylases and heating program in the process of pureeing. Therefore, for a given sweet potato variety, it is expected that cured and stored roots with increasing amylase activities will produce purees which are sweeter and less starchy than those of the just-harvested (green) roots. However, there is a genotype difference in the amounts of maltose produced in the cooked sweet potatoes. Takahata *et al.* (1994) classified sweet potato varieties into high, moderate and low maltose formation after steaming. The genotypes with high maltose formation in cooked roots tended to have early gelatinization of starch granules (< 70°C) and ß -amylase with high heat stability up to 78 - 82°C. A new sweet potato breeding line, Kanto 116, was developed in Japan; this genotype has starch with pasting temperature of 51.4 – 52.6°C, approximately 20°C lower than those in the common sweet potato cultivars (Katayama *et al.*, 2002).

Processing of Sweet Potato Purees

Over the years, techniques have been developed for puree processing in order to produce purees with consistent quality, as mentioned above, despite the variations due to cultivar differences and post-harvest practices. Several methods for sweet potato puree processing were developed since 1960's, and the subject was reviewed by Collins and Walter (1992), Kays (1985) and Woolfe (1992). Process operations for pureeing of sweet potatoes (Figure 1) involve washing, peeling, hand-trimming, cutting, steamed blanching or cooking, and grinding into purees which can be subjected to canning or freezing for preservation.

Washing: Sweet potatoes are stored without removing the dirt for prolonging storability. In the United States, prior to delivery to the fresh root markets, stored sweet potatoes are passed through the packing line for washing, treating with fungicide and sizing. The roots are generally unloaded from the pallet bins into a tank of water, conveyed to high-pressure spray washers wherein water at 250 *psi* is directly sprayed at the surface of sweet potatoes as they tumble over rotating brushes. The washed roots are then sorted by size using pitch roller sizers or electronic sensors (Boyette *et al.*, 1997). The size number 1 roots are selected and packed in carton boxes for table stock markets. The misshapen, undersized or jumbo-sized roots, about 30% of the crop, are considered as the rejects and offered to the processing companies. In places where the whole harvest is delivered to the processing factories, sweet potatoes can be washed with revolving drum washer. Truong *et al.* (1990) described a low-cost washer made of an empty drum with rotating frame holding brushes and having a capacity of 300 kg roots/hr.

Peeling and Rewashing: Prior to peeling, the cleaned roots can be preheated in hot water for a short time to provide some benefits including reduction of peeling time and enzymatic discoloration by polyphenolic oxidase (Bouwkamp, 1985). However, several investigators reported that preheating treatment of the unpeeled roots is not necessary (Edmond and Ammerman, 1971). Sweet potato peel can be removed by abrasive rollers, lye solutions, a combination of lye and steam peeling or high pressure steam. In lye peeling, cleaned roots are conveyed into 10-22% lye solution at 104°C for 3 to 6 min and then transferred to a rotary washer with high-pressure water spray to remove the lye residue, loosened peel and adhere softened tissue. Peeling losses range from 20-40% of the raw material depending on the lye concentration, residence time and root sizes (Scott *et al.*, 1970). Due to the issues on equipment corrosion and waste disposal, lye peeling is no longer a common method in the industry.

Abrasive peelers with capacity of few hundreds to over a thousand kg roots/hr can be used in peeling sweet potatoes (Kays, 1985; Taylor, 1982; van Hal, 2000). High-pressure steam peeling developed by Harris and Smith (1985, 1986) is being used by many sweet potato processing companies. The technology is referred as a thermal blast process in which the roots are enclosed for a short time (20 to 90 sec) in a chamber pressurized with heated steam, followed by an instantaneous release of pressure. As the pressure suddenly release, the super-heated liquid water beneath the skin surface immediately flashed into vapor, and blasted the peel off the roots. This process can be automated, result in less peeling loss than lye peeling, and produce a product with less enzymatic discoloration (Smith *et al.*, 1980). Studies on the effect of lye peeling on amylase activities, starch hydrolysis, phenolic degradation and carotene loss on the surface of sweet potato roots were conducted by Walter and Schadel (1982), Walter and Giesbrecht (1982). Hagenimana *et al.* (1992) has shown that α-amylase is strongly localized in the periderm, the vascular cambium and the anomalous cambium of sweet potato roots while β-amylase is abundant and well distributed throughout the root. During lye peeling, heat and alkali gelatinize starch in the root outer layers where thermostable α-amylase results in starch conversion into maltose and dextrins. However, there is limited understanding in these aspects of the steam flash peeling on the surface of sweet potato roots.

Trimming and Cutting: Peeled sweet potatoes are next conveyed along a trimming and inspecting line for trimming the surface blemishes and fibrous ends and removing the diseased roots. The materials are then fed to size reduction machine for cutting into slices, strips and cubes or grinding into fine particles using a hammer mill or pulp finisher. Cutting and grinding machines with capacity up to over 1000 kg/hr are being used for this operation.

Pureeing Processes: The techniques that have been developed for processing sweet potato into purees are illustrated in Figure 1. The purees can be simply produced by steam cooking of the peeled roots, chunks, slices, strips, cubes or ground particles, and passing the cooked materials through a pulp finisher. However, the aforementioned challenges became an issue in getting the product with consistent quality. Addition of α- and β-amylases can be applied to obtain the desired amount of starch conversion (Hoover, 1966; Szyperski *et al.*, 1986). This method, however, introduces food additives to the process that are usually disliked by consumers. Another approach employs the enzyme activation technique using the endogenous amylolytic enzymes for starch hydrolysis (Hoover and Harmon, 1967), and this process is now commonly used in the food industry. As shown in Figure 1, the peeled sweet potatoes can be either cut into cubes of 2 cm, strips of 2 x 2 x 6 cm and slices of 0.5 - 0.95 cm thick (Walter and Schwartz, 1993; Truong *et al.*, 1994) or mashed using a hammer mill with rotating blades to chop and push the materials through a 1.5 – 2.3 mm mesh screen (Szyperski *et al.*, 1986). Next, the materials are steamed blanched at 65 to 75°C which activates the amylases and gelatinizes the starch for hydrolysis. For the process with slices, strips and cubes, comminuting the blanched materials into puree is carried out at this point using the hammer mill. The blanched puree is pumped into a surge tank and hold at 65 - 75°C for further starch hydrolysis depending on the targeted maltose levels. Raw sweet potato mash as a source of amylases can be optionally added at this stage to increase starch conversion. Alpha- and ß- amylases hydrolyze the starch producing maltose, maltotriose, glucose and dextrins.

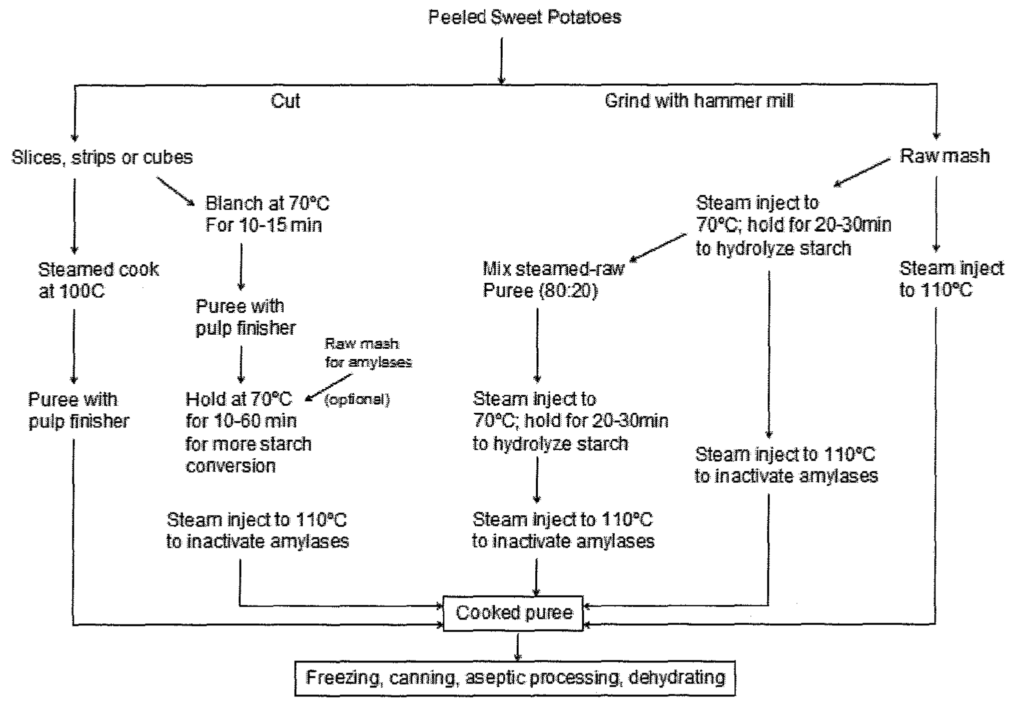

Figure 1. Different processes for sweet potato puree production.

The majority of maltose production is likely completed in the first few minutes of the starch conversion process. Hoover and Harmon (1967) found maltose is the only sugar produced and the majority of maltose was produced in the first 10 minutes of cooking at temperatures of 70 to 80°C. McArdle and Bouwkamp (1986) also reported that rapid heating of raw sweet potato slurries to 80°C may be optimal for starch conversion. However, further decreases in the molecular size of starch and dextrins occur for up to 60 minutes resulting in the purees with high maltose content and low apparent viscosity (Walter *et al.*, 1976; 1999). In order to control the process to produce a consistent product, the length of conversion time can be adjusted from a few minutes to 1 hour depending on the starch content and amylase activity in the raw materials. After starch conversion, the temperature is raised to 100 - 110°C in a heat exchanger to inactivate the enzymes, and a final grinding step will be carried out with the use of a pulp finisher to obtain the smooth puree. The temperature and time program in the described pre-cook/finish cook process has significant effects on the puree quality. A very fast heating procedure tended to result in puree with low levels of maltose and high viscosity, and a temperature and time program that allows sufficient amylase-hydrolysis on gelatinized starch would produce sweet and more flowable purees (Walter and Schwartz, 1993; Ridley *et al.*, 2005).

The developed technologies for puree processing were based mainly on the orange-fleshed sweet potato cultivars with high ß-carotene, low dry matter (18-21%) and low starch content [8-10% on fresh weight basis (fwb)] (Walter and Schwartz, 1993; Yencho *et al.*, 2008). This sweet potato type has moist texture after cooking, produces purees that are viscous, but flowable, and can be handled in various processing operations (Truong *et al.*, 1995; Coronel *et al.*, 2005). On the other hand, sweet potatoes with white, yellow and purple flesh colors have higher levels of dry matter (25-38%) with potentially different starch properties (Walter *et al.*, 2000), which may present challenges for the commercial production of flowable purees from these materials. Therefore, the processing hurdle in pureeing these sweet potato types could be overcome by either addition of water to decrease the solid levels of the material to 18-21%, amylase hydrolysis of starch components, or a combination of the two treatments. For cost-effective reasons, water addition can be adapted as a simple approach in processing of purple-fleshed sweet potato purees that have flowability similar to the purees from the orange-fleshed sweet potatoes (Steed and Truong, 2008).

Packaging and Preservation of Sweet Potato Purees

Canning and Freezing: The finish-cooked puree can be packaged in cans and retorted to produce shelf-stable product. The puree can also be filled in plastic containers for refrigerated or frozen storage (Collins and Walter, 1992; Kays, 1985; Pérez-Díaz *et al.*, 2008; Walter and Wilson, 1992). Ice *et al.* (1980) and Creamer *et al.* (1983) reported that pH adjustment of sweet potato puree to 1.5, 4.5 and 11.5 prior to filling in jars followed by pasteurizing at 90°C could prolong the shelf-life of the product up to 9 months at room temperature. Preservation by canning for low acid food such as sweet potato purees (pH, 5.8 – 6.3) usually involves excessive thermal treatment of the product because heat transfer in the puree is mainly by conduction. Excessive thermal treatment of the product also results in severe degradation of color, flavor, texture, and nutrients. An example is the institutional-size can size 607x 700 which is required to retort for over 165 minutes at 121 °C (Lopez, 1987). The slow- rate of heat transfer from the wall to the center of the can to attain commercial sterilization of the product limits the maximum can size of number 10 for canned sweet potato purees. This size limitation is another obstruction for the wider uses of sweet potato purees as a food ingredient in the food industry. Other issues associated with canning include the difficulty in handling, opening and dispensing of the product, and disposal of emptied cans. Nevertheless, canning does not have the need for special storage, lower capital investment and unit of production is less when comparing to refrigerated and frozen puree.

Frozen puree is an established method for preservation which provides the lower degradation on nutritional and sensory quality as compared to can processing. However, preservation by freezing requires considerable investment in frozen distribution and storage as well as space, energy, time-consuming, and poorly controlled defrosting treatment before use. Currently, only limited amount of canned and frozen sweet potato purees are commercially produced by a few companies in the U. S. and Japan.

Microwave-assisted Sterilization and Aseptic Packaging: Aseptic processing is considered as a potential alternative to overcome the stated problems associated with canning and low temperature preservation. As opposed to conventional canning, the use of high temperature for a short period of time in aseptic processing can produce a higher quality product with equal or better level of microbiological safety as that in a conventional canning system. Smith *et al.* (1982) described an improved canning process for sweet potato purees which involved flash sterilization and followed by aseptic filling, that resulted in a shelf-stable and high quality product. However, scaling-up of the technology for achieving beyond the cans and process validation were not carried out for commercial development. Since then, further application of aseptic processing and packaging technology of food products in flexible containers, has not been successfully carried out for purees from sweet potatoes and other vegetables.

Recently, a process for rapid sterilization and aseptic packaging of the orange-fleshed sweet potato purees using a continuous flow microwave system operated at 915 MHz has been successfully developed (Coronel *et al.*., 2005). This process has the advantage of avoiding long retort processing schedules, maintaining high quality retention, and producing shelf-stable products. The resulting product packed in flexible plastic containers had the color and viscosity comparable to the non-sterilized puree and was shelf-stable for at least 12 months. Purple-fleshed sweet potato purees were also successfully processed into high quality aseptic product using the continuous flow microwave system (Steed *et al.*., 2008). With this technology, shelf-stable purees with consistently high quality can be packaged into virtually unlimited container sizes (up to 300 gallons) for conveniently utilizing as food ingredients in the food processing industry. This technology can be extended to highly viscous biomaterials and purees from other fruits and vegetables. In this new process, sweet potato puree is loaded into the hopper, and pumped through the system. Microwaves are generated from a 60 kW, 915 MHz microwave generator and delivered to the puree by a waveguide of rectangular cross-section which is split into two sections and led to two specially designed cylindrical applicators. The puree is preheated to 100°C in the lower applicator, then to sterilizing temperatures of 130 - 135°C in the upper applicator, stayed in the holding tube for 30 sec, rapidly cooled in a tubular heat exchanger, and then aseptically packaged in aluminum-polyethylene laminated bags (Coronel *et al.*., 2005; Simunovic *et al.*, 2006).

In microwave processing, dielectric properties have a major role in determining the interaction between puree and the electromagnetic energy. Matching the dielectric properties of the material and the required microwave energy for adequate thermal treatment is very important to avoid over- or under- heating in aseptic processing of sweet potato puree (Coronel *et al.*, 2005; Fasina *et al.*, 2003a). The variation in chemical composition of the sweet potato purees is due to cultivars and post-harvest handling of raw materials, as described above, which may affect the microwave heating behavior of the purees. Brinley *et al.* (2008) developed predictive equations for dielectric constant and dielectric loss factor as a function of processing variables and puree composition such as temperature, moisture, sugar, and starch in the purees. The predictive equations are helpful in scaling up a continuous microwave heating system as well as determining the microwave heating patterns of purees from sweet potatoes with varying flesh colors for commercial operations. A technique for microbial validation of the process using biological indicators containing spores of thermal resistant bacteria (*Geobacillus stearothermophilus* and *Bacillus subtilis*) was also developed (Brinley *et al.*, 2007). Other technical aspects associated with the scale-up of this technology such as the application of static mixing devices to improve the uniformity of temperature distribution and process control parameters for extended operating times have been evaluated (Kumar *et al.*, 2008).

The first commercial venture on aseptically packaged sweet potato puree using this microwave-assisted sterilization technology has been carried out by a new company in North Carolina, USA. This development opens up a new market opportunity for the sweet potato industry, and potentially increases the utilization of sweet potato purees as functional ingredients in various food products.

Quality of Sweet Potato Purees

Color and Flavor: Discoloration of the peeled and cooked sweet potatoes can affect the puree color. Enzymatic discoloration is characterized by a brown, dark gray or black color. It occurs when polyphenol oxidase catalyzes the oxidative polymerization of phenolic acid during peeling and size reduction of sweet potatoes. This type of discoloration can be minimized or prevented by heat inactivation of the enzymes, lowering the pH with acidulants, or using inhibitors such as sulfite and ascorbic acid (Walter and Wilson, 1992). The non-enzymatic discoloration shows the gray, black or green color upon exposing the cooked sweet potatoes to air. This "after-cooking darkening" is caused by phenolics complexing with metals especially ferrous iron. Sodium acid pyrophosphate (SAPP) which has a strong affinity to metal ions is effective in preventing the non-enzymatic discoloration (Hoover, 1964). SAPP at concentration of about 0.5% has been widely used in the blanching medium or added directly to the material to enhance the color of sweet potato purees. Citric acid added to the puree at 0.2% can preserve the bright orange color of the product (Bouwkamp, 1985). Among the preservation methods, the puree color is greatly degraded by excessive heat treatment during canning caused by the Maillard browning reaction between sugars and amino acids. Frozen storage has minor color changes over 6 months at -17ºC (Collins *et al.*, 1995). For microwave processing and aseptic packaging, high color retention of purees from both orange- and purple-fleshed sweet potatoes has been reported (Coronel *et al.*, 2005; Smith *et al.*, 1982; Steed *et al.*, 2008).

The flavor of purees, as in baked sweet potatoes, is dependent on cultivars, curing, storage and cooking methods (Hamann *et al.*, 1980; Wang and Kays, 2001). Starch hydrolysis and maltose formation during cooking is important in the flavor quality of cooked sweet potatoes (Koehler and Kays, 1991; Sun *et al.*, 1994; Walter *et al.*, 1975). Walter and Schwartz (1993) reported that approximately 52 - 82% of starch in Jewel sweet potatoes was hydrolyzed, depending on the heat treatment. Maltose is the predominant sugar in the purees from various cultivars (Table 1) followed by sucrose, glucose, and fructose (Brinley *et al.*, 2008; Ridley *et al.*, 2005). Wider ranges of these sugars and sweetness in cooked sweet potatoes were reported by other investigators (Chattopadhyay *et al.*, 2006; Kays *et al.*, 2005; Truong *et al.*, 1986). Aside from the sugars, the release of bound compounds (e.g. from glycosides) and a group of terpenoids such as linalool, geraniol and α-copaene contribute to the aroma of baked and microwaved sweet potatoes, but they were absent in the boiled samples (Wang and Kays, 2001). Thirty volatile compounds have been identified in baked sweet potatoes (Purcell *et al.*, 1980). Several compounds such as 2, 3-pentanedione, 2-furyl methyl ketone, 5-methyl-2-furaldehyde and linalool were correlated with the good sweet potato flavor (Tiu *et al.*, 1985).

Rheological Properties: The rheological behavior is an important property of purees processed from fruits and vegetables and it has been studied by numerous researchers. Krokida *et al.* (2001) compiled data of several fruit and vegetable products and listed values for consistency coefficient and flow behavior index along with the corresponding ranges of temperature and concentration. In the presence of starch, sweet potato purees are naturally viscous and thicker than other processed purees from other commodities such as carrots and tomatoes. Sweet potato purees display shear thinning behavior with a yield stress, as most of fruit and vegetable purees.

Table 1. Sugar Content (% fresh weight) of the sweet potato purees

Cultivar	Glucose	Fructose	Sucrose	Maltose
Beauregard	2.2	1.8	3.3	7.2
Bon 99-447	0.7	0.5	2.2	7.2
Covington	1.5	1.1	3.7	6.1
FTA 94	0.3	0.2	1.1	3.8
Hernandez	2.8	2.3	3.0	7.4
NC 415	1.6	1.2	1.7	9.3
Norton	1.5	1.8	2.3	7.3
O'Henry	1.9	1.7	1.7	7.6
Okinawa	0.5	0.3	1.3	3.7
Picadito	0.6	0.4	1.14	4.1
Porto Rico	1.3	1.1	3.3	8.8
Pur 01-192	0.3	0.2	1.1	3.6
Suwon 122	0.2	0.1	1.3	3.9

Source: Brinley *et al.,* 2008.

In studying the relationship between rheological characteristics and mouthfeel of sweet potato purees, Rao *et al.* (1975a) found sweet potatoes to exhibit non-Newtonian, pseudoplastic behavior that fits the Herschel-Bulkley model. Yield stresses of the purees from eight different cultivars with cream, yellow and orange flesh color in their studies ranged from 230 to 663 dyne/cm^2 (23 – 66.3 Pa) (Rao and Graham, 1982). Consistency coefficient values ranged from 17.9 to 248.1 dyne-s/cm^2 (1.79-24.8 Pa-s) and flow behavior index values varied from 0.333 to 0.564. Apparent viscosity at 97.2 rpm in a coaxial cylinder viscometer ranged from 534 to 2893 centipoise (0.534 – 2.89Pa-s) among the puree samples of the tested cultivars over two months of root storage. Purple-fleshed sweet potato purees with solid content adjusted to 18% as that of the orange-fleshed sweet potato purees also exhibited pseudo-plastic behavior with the flow properties, apparent viscosity and yield stress within these ranges (Steed and Truong, 2008). Both apparent viscosity and yield stress significantly correlated with the mouthfeel attribute of sweet potato purees (Rao *et al.*, , 1975b), and in general they appear to decrease with length of root storage (Rao *et al.*, 1975a). Purees from cured roots were slightly, but not significantly, lower in apparent viscosity than those made from uncured roots (Ice *et al.*, 1980; Hamann *et al.*, 1980). Analysis of viscometric properties with the use of Bostwick consistometer and different types of rotational viscometers has been used to assess the quality of sweet potato purees.

Apparent viscosity of sweet potato puree decreases with increasing shear rate and temperature (Figure 2). Kyereme *et al.* (1999) studied the effect of temperature from 15°C to 90°C on apparent viscosity of sweet potato puree with a shear rate sweep of 0.001 to 921/s. The flow behavior of sweet potato puree as affected by temperature was well represented by either the Herschel-Bulkley or Modified Casson models. The models can adequately predict the apparent viscosity of sweet potato puree at 50°C but they did not perform well at higher temperatures. Ahmed and Ramaswamy (2006) observed a deviation in rheological behavior of sweet potato puree infant food at and above 65°C that was possibly caused by gelatinization and possible formation of amylase-lipid complex of starch as confirmed by two distinct DSC (Differential Scanning Colorimeter) thermal transition peaks at 54°C and 95.5°C. Brinley *et al.* (2008) reported significant decrease in apparent viscosity of sweet potato puree at 130°C at which the puree was sterilized in the microwave-assisted aseptic packaging.

Sweet potato purees are usually thickened with temperature decreases that may lead to a difficulty in pumping during the processing operations but the phenomenon can be beneficial in providing the desired textural properties in processed food products (Steed *et al.*, 2008). Amylose and amylopectin in the sweet potato puree form a gel network upon cooling. Aside from the steady-shear viscometry described above, the small-amplitude oscillatory tests have been used to characterize the viscoelastic behavior of sweet potato purees.

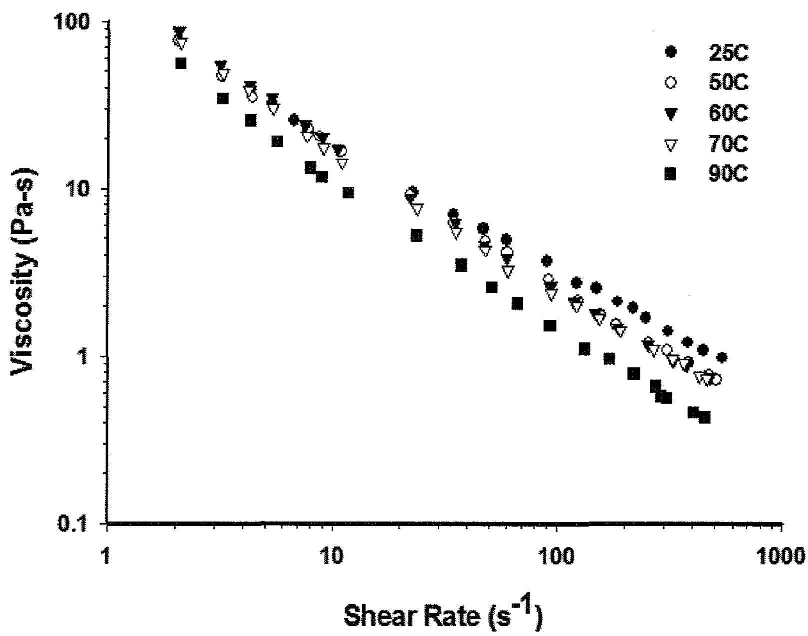

Figure 2. Apparent viscosity of orange-fleshed sweet potato puree cv. Beauregard at different temperatures (Truong, unpublished data).

Fasina *et al.* (2003b) and Ahmed and Ramaswamy (2006) reported that purees exhibit gel behavior illustrated by a larger storage modulus (G', the elastic component) than loss modulus (G”, the viscous component) through oscillatory rheology. The parallel slopes of G’ and G” with G’ greater than G” throughout the frequency range define the solid-like behavior of a food material (Steffe, 1996). This gel network was further strengthened by the addition of alginate and calcium salts to form a firmer puree (Fasina *et al.*, 2003b; Truong *et al.*, 1995). The puree processing methods affect the viscoelastic properties and textural profiles of restructured products made from sweet potato purees (Walter *et al.*, 1999).

Nutritional Values: The nutrient content of sweet potato purees and pastes from varieties with different flesh color is shown in Table 2 (Brinely *et al.*, 2008). It should be noted that the values of the paste samples (> 21% dry matter) would be lower since dilution needs to be carried out for having flowable purees during processing. Sweet potato purees have low protein and fat content, but they are high in calories, minerals such as potassium, phosphorus, magnesium and calcium, and a relatively good source of dietary fiber, 2.0 – 3.2 g/100g fresh weight basis (fwb) (Bovell-Benjamin, 2007; Woolfe, 1992; Yencho *et al.*, 2008). The glycemic index (GI) of steamed, baked or microwaved sweet potatoes were about 63-66, as compared to 65-101 for potatoes cooked by these methods (Soh and Brand-Miller, 1999).

Table 2. Nutritional value (% fresh weight) of purees from various sweet potato genotypes

Cultivar	Dry matter	Starch	Total Sugar	Protein	Lipid	Ash
Beauregard	19.5	2.3	14.5	0.4	0.1	0.7
Bon 99-447*	24.7	10.6	10.6	1.9	0.1	1.0
Covington	19.3	1.9	12.4	0.4	0.1	0.8
FTA 94*	33.1	10.2	5.4	0.7	0.2	1.1
Hernandez	23.3	3.83	15.4	0.5	0.1	1.0
NC 415*	30.0	12.0	13.8	0.5	0.1	0.9
Norton*	25.9	6.6	12.7	0.4	0.1	0.8
O’Henry	20.6	2.7	12.9	0.4	0.1	0.8
Okinawa*	32.0	3.2	5.8	0.6	0.1	0.9
Picadito*	31.3	12.5	6.2	0.3	0.1	0.8
Porto Rico*	26.9	2.8	14.5	0.5	0.1	0.8
Pur 01-192*	32.5	13.2	5.3	0.4	0.2	1.0
Suwon 122*	34.4	11.3	5.5	0.6	0.2	1.0

*Dry matter should be adjusted to < 21% for flowable purees Source: Brinley *et al.*, 2008.

Orange fleshed-sweet potato purees are rich in ß-carotene (Table 3). A wider range of β-carotene content in cooked orange-fleshed sweet potatoes, 6.7 – 16.0 mg/100g fwb, has been reported by different investigators (Huang *et al.*, 1999; Namutebi *et al.*, 2004; Bovell-Benjamin, 2007). The sweet potato carotenoids exist in an all *trans* configuration which exhibits the highest provitamin A activity among the carotenoids. van Jaarsveld *et al.* (2005) and Tanumihardjo (2008) advocate the increased consumption of orange-fleshed sweet potatoes as an effective approach to improve the vitamin A nutrition in the developing countries. Epidemiological studies indicated the beneficial effects of high carotene diets in reducing the risks of cancer, age-related macula degeneration and heart diseases (Kohlmeier and Hasting, 1995; Pandey and Shukla, 2002; van Poppel and Goldbohm, 1995). Carotenoids can be isomerized by heat, acid, air or light during puree processing and storage. When exposed to heat, the molecule may transform to a *cis* configuration typically at the 9, 13, and 15 carbon positions. The *cis* form reduces pro-vitamin activity but color remains mostly unaffected. Extremely high temperature processing will cause fragmentation products and release of volatile compounds. Chandler and Schwartz (1988) studied the changes in ß-carotene and its isomerization products as a result of blanching, canning, dehydrating, and cooking.

The length and severity of the heat treatment increased ß-carotene loss and isomerization. Blanching, lye peeling, and pureeing actually showed an increase in ß-carotene content but this increase was attributed to enhanced extraction efficiency due to the heat treatment. However, other common sweet potato processing treatments showed significant reductions in ß -carotene content: steam injection – 8.0% loss, canning 19.7% loss, microwaving - 22.7% loss, and baking - 31.4% loss (Chandler and Schwartz, 1988). Lessin *et al.* (1997) quantified ß-carotene isomers after canning sweet potatoes. The total ß-carotene content increased by 22% from 256.5mg/g (db) in the fresh root to 312.3 mg/g (db) in the canned product which was attributed to increased extraction efficiency.

Table 3. Phytonutrients in orange- and purple-fleshed sweet potatoes

Varieties	Flesh color	Dry matter (g/100g)	□-carotene (fwb) (mg/100g)	Antho cyanins[1]	Total phenolic[2]
Beauregard	Orange	20.5	9.4	na	88.9
Covington	Orange	20.3	9.1	3.8	58.4
Stokes Purple	Dark purple	36.4*	na	80.2	401.6
NC 415	Dark purple	29.0*	na	69	652.5
Okinawa	Light purple	30.0*	na	21.1	458.3

*Dry matter needs to be adjusted to 18-20% for flowable purees; na = not analyzed.
[1]mg cyanidin-3-glucoside/100g fw; [2]mg chlorogenic acid/100g fw.
Sources: Truong *et al.* (2007); Steed and Truong, 2008; Yencho *et al.*, 2008.

After canning however, some of the *trans*- form was transformed to *9-cis* (25.3 mg/g), *13-cis* (76.6mg/g), and *15-cis* (19.4mg/g) forms while 191mg/g (db) remained in the *trans* configuration. A loss of less than 15% carotene content was observed by microwave sterilization and aseptic packaging of orange-fleshed sweet potato purees (Truong, unpublished data). Thus, the carotene-rich sweet potato purees can be a functional food ingredient which can help reduce the risk of chronic diseases and vitamin A deficiency in many parts of the world.

The cooked paste of the purple-fleshed sweet potatoes has attractive reddish-purple color with high levels of anthocyanins and total phenolics (Table 3). The flowable purees with a solid content of 18% made from this material had total phenolic and anthocyanin contents of 314 mg chlorogenic acid equivalent/100g fwb and 58 mg cyaniding-3-glucosdie equivalent/100g fwb, respectively. The 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was 47 μmol trolox equivalent/f fwb and oxygen radical absorbance capacity (ORAC) of 26 μmol trolox equivalent/f fwb (Steed and Truong, 2008). Therefore, the purple-fleshed sweet potato purees have polyphenolic content and antioxidant activities in a competitive level with other food commodities known to be a good source of antioxidants such as black bean, red onion, black berries, cultivated blueberries, sweet cherries and strawberries (Wu *et al.*, 2006) 2006). Several clinical studies indicated that consumption of purple-fleshed sweet potatoes may have potential health benefits against oxidative stress associated with liver injury (Suda *et al.*, 2008) and other chronic diseases (Suda *et al.*, 2003).

Utilization of Sweet Potato Purees in Processed Foods

Sweet potato purees has been used as an ingredient in numerous food products, including baby food, casseroles, puddings, pies, cakes, ice cream, yogurt, leather, bread, patties and soups (Collins and Walter, 1992; Collins *et al.*, 1990; Collins and Washam-Hutsell, 1986; Hoover *et al.*, 1983; Silva *et al.*, 1988; Woolfe, 1992; Yasufumi and Shigeki, 2000). The most successful commercial application of sweet potato puree is for baby food.

Recognizing the similarity in nutrient content of sweet potatoes and fruits, Truong (1987) conceptualized a novel strategy on value-added processing of sweet potatoes into products that have been traditionally produced from fruits. This novel approach was expanded to the development of a process for producing sweet potato puree-based beverages with sensory quality and nutrient content similar to fruit juices. Both orange- and purple-fleshed sweet potatoes were utilized, and the beverages were produced either in a concentrate form for reconstitution to a single strength of 100% sweet potato drinks, or in combination with other fruit juices and flavorings (Truong and Fementira, 1989, 1990). Such development raised interest among research institutions in several sweet potato producing countries including India, Japan, Malaysia, and the United States (Payton *et al.*, 1992; KNAES, 1996; Sankari *et al.*, 2002; Tan *et al.*, 2004). Several patented processes on utilization of sweet potato purees in fruit and vegetable beverages were developed in Japan and the United States (Gladney, 2005; Payton *et al.*, 1992), and currently there are several fruit and vegetable drinks with sweet potato purees as an ingredient being commercialized in these countries. Other commercial utilization of sweet potato puree includes jam and ketchup (Truong, 1994; Fawzia *et al.*, 1999). Restructured products from sweet potato puree with the use of gelling agents such as carboxymethyl cellulose, hydroxymethyl cellulose and alginate-calcium system have also been developed. These products, simulated-baked sweet potatoes and restructured French fries have good sensory quality and textural properties (Truong and Walter, 1994; Truong *et al.*, 1995; Utomo *et al.*, 2005). Recently, sweet potato purees have been used in developing carotene-rich curd and fermented beverages with high antioxidant activity (Mohapatra *et al.*, 2007; Saigusa *et al.*, 2005). With the recent commercial development of the microwave-assisted processing and aseptic packaging of sweet potato purees (Coronel *et al.*, 2005; Steed *et al.*, 2008), it is expected that more processed food products from the puree will be developed. In the U. S., sweet potato puree has been used for dehydrating into flakes or powder for various food applications that is described in the following section.

DEHYDRATED POWDER / FLOUR AS FUNCTIONAL INGREDIENT

Sweet potato roots can be processed into dehydrated forms such as dried chips and flour for storage and uses in food preparations (Peters and Wheatley, 1997). The flour can add natural sweetness, color, and flavor to processed food products. It can also serve as a source of energy and nutrients and minerals (Table 4), and contributes to the daily nutrient needs for β-carotene, thiamin, iron, vitamin C, and protein. Sweet potato flour provides 14% - 28% of the dietary reference intake (DRI) for magnesium and 20 - 39% for potassium (van Hal, 2000). For individuals diagnosed with celiac disease or with allergies to the gluten in wheat, sweet potato flour can serve as an alternative.

Food allergies have become a public health issue in many countries (Maleiki, 2001). About 5% of the population has serious allergies to some foods, including the gluten in wheat and other cereals including rye, barley, triticale, and oats, (Mannie, 1999, Caperuto *et al.*, 2000). In addition, the home production of a simple traditional processed sweet potato foods, as practiced by women and children in tropical countries could increase family income (Alcobar and Parrilla, 1987). Thus, sweet potato flour production for human feeding will aid in promoting year-round consumption, decreasing losses of food, increasing the economic value of the crop besides increasing the efficiency of the food delivery system.

Table 4. Composition of sweet potato flour*

Parameter	Native Flour	Spray Dried**	Drum Dried	Hot air Dried (Cabinet dried)
Protein	6.6	3.18	6.5	6.3
Fat	1.0	0.61	1.1	1.1
Total dietary fiber	17.5	5.85	17.6	17.2
Ash	1.0	2.7	1.3	1.1
Phosphorous	0.1	-	0.12	0.11
Total carbohydrates	73.0	85.23	73.8	73.6

*Dry weight basis.

**contains added dextrins. Source: Avula *et al.* 2006; Grabowski *et al.*, 2008.

Sweet potato flour is used as a raw material for processing into other products. A variety of products such as doughnuts, biscuits, muffin, cakes, cookies, extruded products, fried chips, ice cream, porridge, brownies, pies, breakfast foods, and weaning foods have been made from sweet potato flour (Greene *et al.*, 2003; Lee, 2005; Toyokawa *et al.*, 1989). In India, dried sweet potatoes grounded into flour are used to supplement flours in bakery products, *chapathis*, and puddings (Nair *et al.*, 1987). Drying of root slices for sweet potato flour production is also practiced to certain extents in many countries in Asia including Bangladesh, China, Indonesia, Japan, Philippines and Vietnam. In Indonesia, fresh roots are sometimes soaked in 8-10% salt solution, a practice which is reported to inhibit microbial growth during drying (Winaro, 1982). In parts of East and West Africa, where there is a pronounced dry season, roots are peeled, sliced, and sun dried for storage. In Peru, sweet potato flour has been produced for decades, to prepare wheat/sweet potato bread (van Hal, 2000).

Processing of Sweet Potato Flour

For sweet potato roots to produce good quality flour, they should be low in total free sugar content, reducing sugar content, ash content, amylase and polyphenol oxidase activities, and have high dry matter with white color (Bovell-Benjamin, 2007; Collado *et al.*, 1997). Roots are still acceptable for processing if the reducing sugars do not exceed 2% on dry weight basis (van Hal, 2000). Generally, controlling the quality of a product is based on the acceptability of the users and food legislation (Bovell-Benjamin, 2007). Dehydration of sweet potato involves washing, peeling, slicing/shredding, blanching, soaking, pressing, and drying (van Hal, 2000; Woolfe, 1992). The losses during peeling and the ease of drying by slicing and shredding have been reported. In traditional practice, the roots, which may or may not be peeled and cooked but more often are directly cut up into pieces and spread out in the sun to dry. They yield dried chips or slices which can be ground in a mortar to flour, and then sieved. Mechanical driers such as cabinet, tunnel, drum, or spray drying as used in large commercial enterprises are highly technical processes using large amounts of energy, which add greatly to the cost of the final product (van Hal, 2000).

Solar Drying: Solar drying is the cheapest technique since it uses free and non-polluting energy with a minimum investment in equipment. Drying of sweet potato root slices in direct sunlight or in a solar dryer is frequently carried out. Both white and colored varieties have been found suitable for solar drying. Drying times vary depending on climatic conditions from 4 h to 5 days. Slices were dried until they reached a moisture content of about 6-10% (Winaro, 1982). The use of dehumidified air increased the drying rates by about 6-8%. However, solar drying has a number of disadvantages, such as poor control of energy input and product quality, interruption of drying caused by cloud, rain, and nightfall and frequent contamination of food by microorganisms, dust, and insects (Woolfe, 1992).

Mechanical Drying: Drying in a cabinet or tunnel dryer is based on the same principle as solar drying, with the difference being that the air is heated by fuel. In this type of dryer, the drying temperature, drying time and air velocity, and hence total dehydration conditions could be controlled. Slices/dices are also subjected to blanching to inactivate the enzyme responsible for browning reactions and soaked in solution containing sulphur dioxide to inhibit enzymatic and non enzymatic reactions for improving color and retaining quality during storage. Sweet potato slices are exposed to drying temperatures between 50°C - 80°C for 4 - 12 h (Avula *et al.*, 2006; Collado *et al.*,. 1997; Hathorne *et al.*,. 2008). Special batch type cabinet dryers for drying sweet potato slices on small and industrial scales were also developed (Eusebio *et al.*, 1996; Truong *et al.*, 1990). Air velocity, slice thickness, and air-dry bulb temperature were the main variables that affected drying rates of sweet potato slices (Diamante and Munro, 1991). The modified Page equation was found to be the best description for the drying curves of sweet potato slices dehydrated to a moisture content of 10%. Antonio *et al.* (2008) studied the influence of osmotic dehydration and high temperature short time drying process on dried sweet potato and found that 150°C for 10 min and 160 °C for 22 min were the best drying conditions for drying of sweet potato slices subjected to osmotic treatment and no osmotic treatment, respectively.

Drum drying is also used for dehydration of sweet potato puree to produce flakes / powder. Walter *et al* (1983) and Valdez *et al.* (2001) dried the cooked and comminuted sweet potatoes in a double drum drier heated with steam at 80 *psi*. The flakes were milled into <60 mesh particles and stored under nitrogen at -20°C. Drum dried sweet potato flakes were prepared by Manlan *et al.* (1985), after treating the sweet potato puree with amylase enzyme to reduce viscosity. Avula *et al.* (2006) prepared drum dried flour by subjecting sweet potato mash to a double drum drier of 60 cm width and 35 cm diameter. The speed of the drum was maintained at 3 rpm with a clearance of 0.3 mm and at a steam pressure of 6 kg/cm^2. The sheets of dried sweet potato were collected, crushed and milled in a hammer mill provided with a 500 μm sieve. Fukazawa and Yakushido (1999) reported that drum-dried the sweet potato mash at 80ºC in the first half of the drying cycle and at 55 ºC to 60ºC in the later part of drying produced flour with good orange and purple color.

Spray drying of sweet potato puree of 18.2% solids was investigated by Grabowski *et al.* (2006). The puree was subjected to pre-treatment with α-amylase at 50°C - 60°C to reduce viscosity and maltodextrin addition to aid in spray drying. Maltodextrin (10-20%) facilitates product recovery by raising the glass transition temperature of the product, thereby reducing stickiness and partially encapsulating the material. The puree was spray dried using a dryer equipped with a 2-fluid nozzle for atomization and a mixed-flow air-product pattern. The pre-drying treatments and drying temperature impacted the final characteristics and functionality of the spray-dried sweet potato powders. It was demonstrated that good quality sweet potato powder can be produced by spray drying with potential applications in food and nutraceutical products.

Modified Flours: The technology in modifying starch has also been applied in developing modified sweet potato flours (Avula *et al.*, 2007a).The most important reaction in the chemical modification of food starches is the introduction of substituent groups (Kim *et al.*, 1996). These chemical modifications are of two types, monofunctional and di - or polyfunctional. Monofunctional reagents react with one or more hydroxyl groups per sugar unit to alter the polarity of the unit, sometimes making it ionic, and markedly influence the rheological properties of the starch. Monofunctional reagents most often used for food starch are acetic anhydride and propylene oxide. The former reacts to produce starch acetate (Moore *et al.*, 1984). The physicochemical properties of acetylated starches depend on their chemical structures, degree of substitution (DS) and acetyl group distributions (Gonzalez and Perez, 2002; Lawal, 2004; Singh *et al.*, 2004). Acetylated sweet potato flour was prepared by treating the native flour with acetic anhydride (Avula *et al.*, 2007a). The native flour (prepared by drying the sweet potato slices at 40 °C and milled into flour and sieved) was mixed with solid $NaHCO_3$ and wetted with distilled water, followed by addition of acetic anhydride. The mixture was allowed to react for 2 h at 40 °C, and later was washed thoroughly with aqueous alcohol (80%) and dried at 40 °C overnight.

During *in vitro* alpha amylolysis of different starch granules, the enzyme attack is rather restricted and is usually from outside inwards, i.e. exocorrosion (Hayashida *et al.*, 1989). On the other hand, *in vivo* the granules are subjected to cumulative actions of salivary amylase, dilute acid (by gastric juices) and pancreatic α- amylase and intestinal microflora and as a result the granules are better digested. The granule degradation was mostly confined to pitting and surface erosion all over. Some researchers have shown 'onion-type' layering of the granules (Tharanathan, 1995). To develop enzyme modified flour, the native flour was subjected to glucoamylase action. The reaction mixture containing native sweet potato flour and the glucoamylase enzyme was incubated at 60 °C for 120 min. It was centrifuged and the sediment was washed with alcohol repeatedly and dried (Avula *et al.*, 2007a).

Storage Stability of Sweet Potato Flour

For prolonged storage of sweet potato flour, the packaging material must be impermeable to vapor and gas, resist tearing, protect against contamination from the environment, and be easy to handle (Furuta *et al.,* 1998; van Hal, 2000). Orbase and Autos (1996) showed the advantage of double packaging (polyethylene/muslin cloth) to prevent lumpiness and loss of color of flour stored in polyethylene and polypropylene bags for 5 - 7 months. Auto-oxidation of carotenoids may take place during storage, leading to loss of color and nutritional value. The stability of β-carotene proved to be strongly and adversely affected by storage temperature and light (Woolfe, 1992). The microbial count of flour stored in different packaging materials did not change over time and was below the tolerable limit (Tardif-Douglin *et al.*, 1993). Out of the four equilibrium sorption models that were evaluated, the Hasley equation gave the best fit to the sorption data. When Hasley equation was used to estimate the thermodynamic functions of sweet potato, it was found that the heat of vaporization and the differential entropy decreased with moisture in an exponential fashion (Millan *et al.*, 2001).

Nutritional Quality of Processed Flour

Nutritional Value: Changes in the nutritional value of the sweet potato roots during processing were found to occur due to peeling, soaking, pre-cooking, and drying steps. Flours from peeled and unpeeled roots were found to be different in composition and the flour from the latter was higher in ash and crude fiber. Shrinkage of the slices and decrease of yield were observed during soaking due to plasmolysis. Reduction in solubles, total sugar, starch, amylase, ash content was also observed. Discoloration of sweet potato slices/shreds resulting in low quality brown flour was observed due to the action of oxidase enzymes. Soaking in 2% citric acid solution resulted in final dehydrated product with a red-yellowish tint due to the caramelization of sugars accelerated by the citric acid (Hamed *et al.*, 1973; Widowati and Damardjati, 1992).

Martin (1984) found that the flours made from microwave baked sweet potatoes had the amount of starch varied from 40-60%, which was much less than the flours from uncooked sweet potatoes (69-85%). The levels of non-reducing sugars and of protein were unaffected, while the levels of reducing sugars were much higher in flours from microwave-baked sweet potatoes. Lowest reduction of total protein, lysine, and methionine during dehydration by solar drying and cabinet drying was observed, with moderate changes at temperatures not exceeding 80°C. Sulphiting treatment given to prevent enzyme darkening of the sweet potato flesh during dehydration can reduce thiamin content of drum dried sweet potato flakes (Hamed *et al.*, 1973; Moy and Chi, 1982). Drum drying process retained more ascorbic acid than sun drying as the latter process exposes ascorbic acid to heat degradation and oxidation. Although the content of most of the amino acids was almost the same for oven and drum-dried flours, the lysine content of the drum-dried flour was substantially lower and resulted in its lower protein efficiency ratio (PER) compared to oven-dried flour. The high temperature (120-140°C) applied during drum drying caused a reaction of the ε-amino group of lysine with reducing groups of carbohydrates which caused the lysine to be destroyed irreversibly and as such to become nutritionally unavailable (Walter *et al.*, 1983). Sammy (1970) compared the chemical composition of spray-dried and cabinet-dried sweet potato flours and found that the products were similar except for the higher moisture content of the cabinet dried flour and the higher sugar (both reducing and total sugars) content of the spray dried flour.

Lipid oxidation of drum dried sweet potato flakes has been a common problem resulting in reduction of lipid content (Walter and Purcell, 1974). Similarly, spray drying exposes more surface area of sweet potato powders, thus allowing oxidation and degradation to take place (Grabowski *et al.*, 2008).A 50-70% decrease in vitamin C was reported for sweet potato flakes, drum dried at high temperatures (Arthur and McLemore, 1955). Spray drying of sweet potato purees significantly decreased total amount of β-carotene and caused isomerization of the molecule which reduces pro-vitamin A activity as described in the previous section. Isomerization of β-carotene was also found to occur during dehydration in a cabinet drier, drum-dryer, microwaving, or baking, with the quantity of isomer formed related to the severity and length of the heat treatment (Kidmose *et al.*, 2007; Woolfe, 1992). Extruded sweet potato flour from orange-fleshed sweet potatoes showed the lowest losses in total carotenoids as compared to cream-fleshed cultivars (Fonseca *et al.*, 2008).

In-vitro Digestibility and Antioxidant Activity: Processed flours which have undergone cooking and drying treatments were more digestible than enzyme modified and acetylated flours (Figure 3). Hot air dried flour was found to be more digestible than drum dried flour, indicating less compactness of the particles in the former. The temperature during hot air drying was more conducive for amylolytic hydrolysis of starch by the endogenous amylases present in sweet potato, which also led to reduction in pasting viscosities (Avula *et al.*, 2006). The higher digestibility of processed flours may be due to comparatively less branching and low molecular weight of the starch constituent fractions (Madhusudhan *et al.*, 1996). The disrupted state of starch granules of drum dried and hot air dried flours would have helped in better penetration of enzyme to facilitate digestion. The degree of amylolysis is dependent on the chemical nature of starch, type of processing, presence of inhibitors, and physical distribution of starch in relation to other dietary components such as cellulose, hemicellulose, and lignin (Rao, 1969; Hale, 1973).

The changes in morphological features have also facilitated better digestibility in enzyme modified flour. Starch digestibility is significantly improved by cooking with either dry or moist heat, or fine grinding (Dreher *et al.* 1981; Leach and Schoch, 1961). Although cooking improved digestibility, a wide variation in digestibility still remained, depending on the cooking conditions.

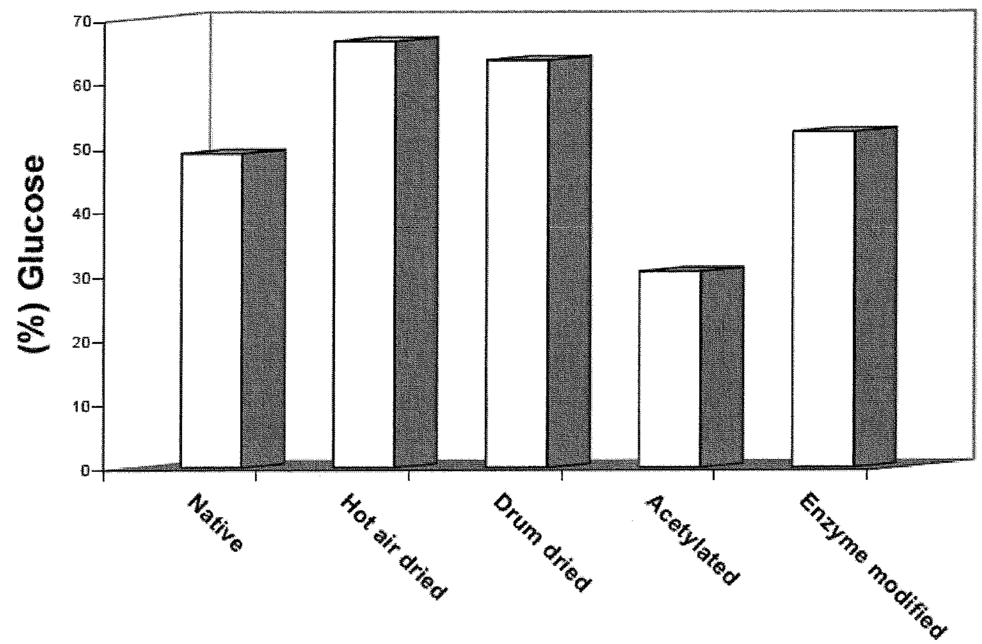

Figure 3. Digestibility of sweet potato flours (adapted from Avula et al. 2006, 2007a).

The effect of degree of substitution (DS) on digestibility was inverse and exponential. Acetylated starches sharply reduced the digestibility of gelatinized starch by pancreatic amylase (Wootton and Chaudhry, 1979). Determination and establishment of differences and changes in starch digestibility in variously treated flours is essential in recommending suitable utilization of these flours. Poorly digested flours may also function like dietary fiber and have therapeutic benefits such as, lowering blood glucose in diabetes, or to aid in weight control (Skrabanja *et al.*, 1999). Restricted digestion of starch is critical for infants and senior citizens having reduced digestive capacity and people with physical exhaustion, emotional stress or medical disorders leading to disturbed digestion (Niba, 2003).

Antioxidant activity of sweet potato flour varies significantly with the flesh color of the roots. The purple-fleshed genotypes have high levels of polyphenolics and antioxidant activity (Teow *et al.*, 2007). Steam blanching increased the reducing power and scavenging DPPH radical effect of sweet potato flours. Contents of total phenols, flavonoids, and anthocyanins in sweet potato flours were positively correlated with the reducing power and scavenging DPPH radical effects (Huang *et al.*, 2006). Four different polyphenolic compounds, namely 4, 5-di-O-caffeoyldaucic acid, 4-O-caffeoylquinic acid, 3,5-di-O-caffeoylquinic acid, and 1,3-di-O-caffeoylquinic acid were identified in freeze dried sweet potato flour. Antioxidant activity of daucic acid derivative was found to be very high (Dini *et al.*, 2006). Sweet potato foliage is rich in total phenolic content and antioxidant activity which are about 8- to 18-fold greater than the roots (Truong *et al.*, 2007). Thus, the dry powder of sweet potato leaves can be a good source of antioxidants and its applications to enhance the functional properties of juices, paste, ice cream and other food ingredients have been initiated (Islam, 2006).

Physical Properties and Functionality of Flour

Sweet potato flour being rich in starch, exhibits unique functional properties which will find its suitability in specific product formulations. However, the properties of sweet potato flour may be influenced by the method of preparation, severity of heat treatment, type of modification, the presence of other components such as fiber, protein, etc. The changes in structural characteristics of starches occurring as a result of modification / treatment may also be responsible for bringing specific functionality to the sweet potato flour. Hence, the limited data available for functional properties of sweet potato flour are different from those of starch since extra constituents available in flour (non- starch polysaccharides, protein, fat, etc), restrict access of water into the starch granules (van Hal, 2000). For example, RVA visco-amylograph pasting parameters of flour, were not correlated to the RVA pasting parameters of the purified starch (Jangchud *et al.*, 2003).

Particle size and morphology: Pre-treating the sweet potato puree with α-amylase and the addition of maltodextrin prior to spray-drying had significant effects on particle size and bulk density of the powder. Typically, as particle size decreases the bulk density will increase, but this was not apparent in spray-dried sweet potato powder. Bulk density was observed to decrease with amylase treatment (Grabowski *et al.*, 2006). This decrease in bulk density did not match the decreasing particle size, and the phenomenon can be explained by the agglomeration of sticky particles during the drying (Goula *et al.*, 2004). The particle size of the sweet potato powder from rotary atomizer was found to be less than half the size of the particle size of the powder made on dryers with 2-fluid nozzle (Grabowski *et al.*, 2006).

When observing particle morphology, some of the granules of enzyme-treated spray dried powder appeared to aggregate as compared to flours without α-amylase addition (Figure 4). These agglomerates take up a larger volume and, thus, would contribute to a smaller bulk density. These aggregated particles may also aid in the slightly increased water solubility of the powders treated with amylase.

Morphological features of starch granules of drum dried and hot air-dried flours resembled each other, and the entire granule population seems to be clustered to form an aggregated mass comprising of several small granules, more so during drum drying (Figure 5). Starch granules of native flour were round, spherical of 4-26 μm, while the size of agglomerated granules ranged from 70-220 μm in drum dried, and 40-130 μm in hot air-dried flours (Avula *et al.*, 2006). Chen *et al.* (2003) reported that the noodle quality was determined by the source and size of the starch granules. Further, the disruption of the granules indicated the complete gelatinization of starch in both drying processes resulting better hydration of the processed flours (Avula *et al.*, 2006). The granular characteristics of starch were partially disappeared in acetylated and enzyme modified flours. Acetylated flour showed indentation as a result of modification, and also the granules appeared as clusters (Figure 5D). The fusion of starch granules in acetylated flour could be attributed to the introduction of hydrophilic groups to the starch molecules, which resulted in increased hydrogen bonding (Singh *et al.*, 2004). Exo-corrosion of enzyme-modified flour (Figure 5E) was noticed, and the penetration of glucoamylase was imminent by the appearance of serrated surfaces and breakage of outer layers in some granules (Avula *et al.*, 2007b).

Rheological Properties: The material composition and conditions under which products are spray-dried can have an effect on the physical properties of the resulting powder. Though the solids concentration in the puree and reconstituted solutions was the same (18%), the puree viscosity was much greater than the powder viscosity (Figure 6).

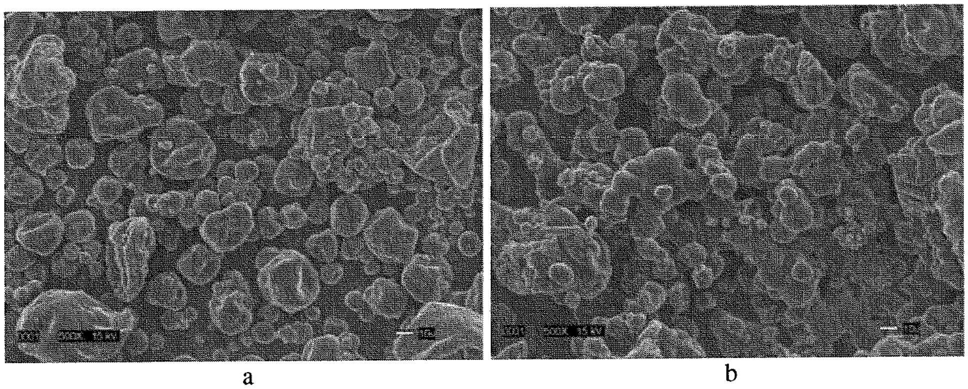

Figure 4. Scanning electron microscope image of spray dried powder. (a). Without amylase treatment, (b) With amylase treatment (adapted from Grabowski et al. 2006).

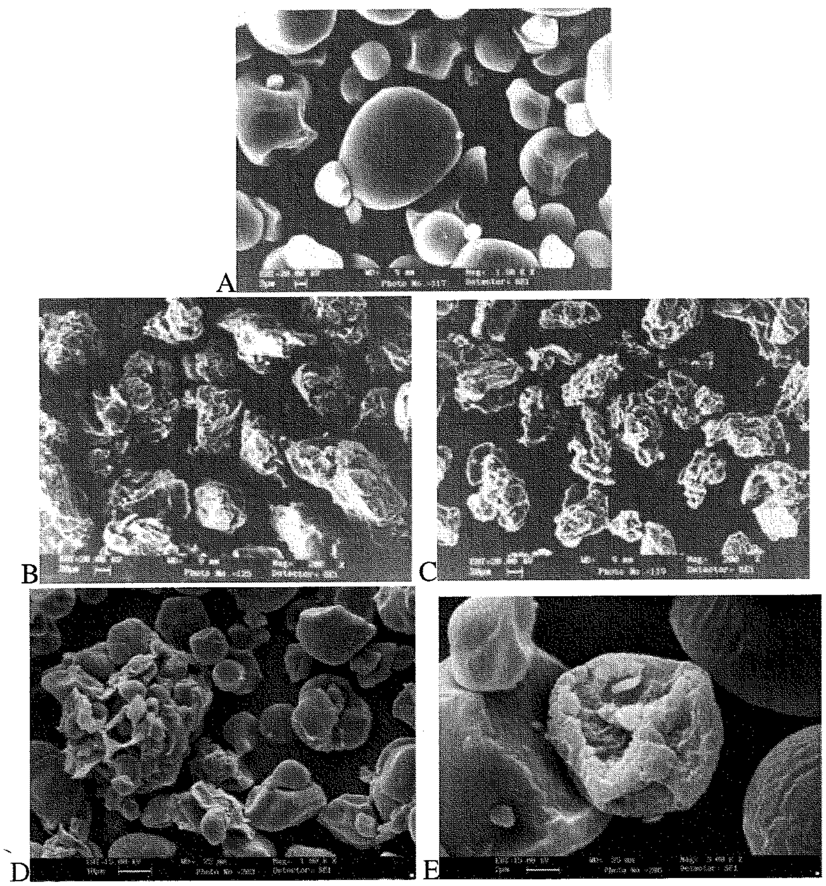

Figure 5. Scanning electron micrographs of starch granules in sweet potato flours. A. Native, B. Drum dried, C. Hot Air Dried, D. Acetylated and E. Enzyme modified (adapted from Avula et al., 2006; Avula unpublished data).

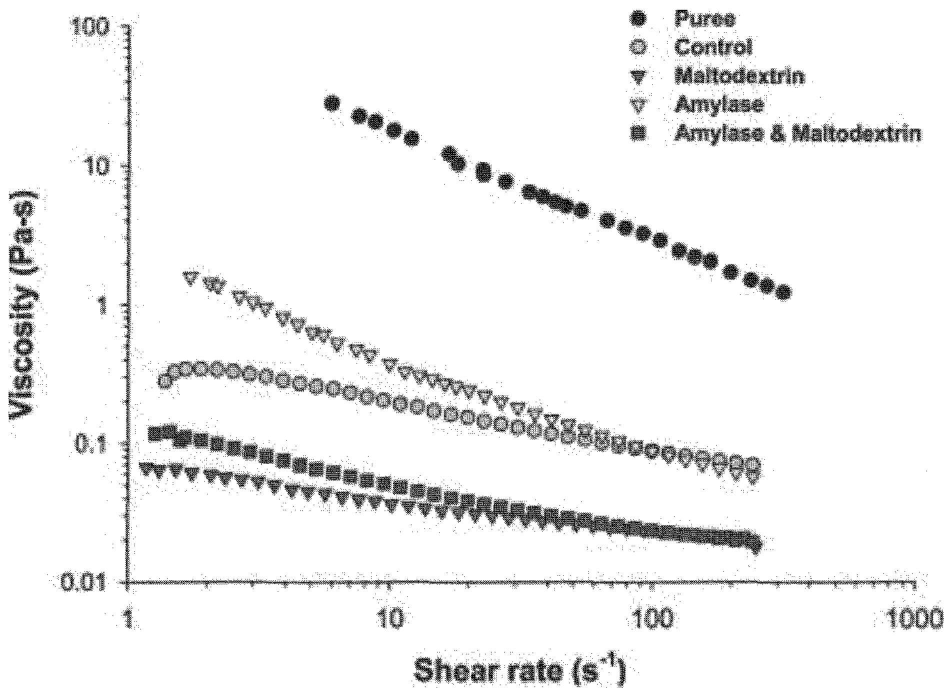

Figure 6. Viscosity of sweet potato puree and reconstituted spray dried powders from 1 to 250 s-1 (adapted from Grabowski et al., 2008).

Starch molecules in the powder are degraded during processing, thus losing the ability to swell and decreasing viscosity (Grabowski *et al.*., 2008). With more of the spray dried powder solubilized into solution, there was less sweet potato solids to create resistance to flow in the mixture.

In order to spray-dry a sticky material like sweet potato puree, maltodextrin is used as carrier to facilitate the drying process by increasing the glass transition temperature of the product. In addition to encapsulation of the sweet potato material by maltodextrin, the interactions of maltodextrin with other polysaccharides present in the powders do not allow the polysaccharides to fully extend in solution, thus decreasing solution viscosity (Grabowski *et al.*, 2006; Vega *et al.,* 2005). Though the sweet potato puree exhibited pseudoplastic behavior which was best fit to Herschel–Bulkley model with distinct yield stress, the flow curve of the reconstituted puree (18% solid) from the spray dried powder did not have a yield stress and fit the power law model. Powder solutions had much lower consistency coefficient values and higher flow behavior index values than the sweet potato puree. The flow behavior index of less than 1 further demonstrates the pseudo plastic behavior of spray dried sweet potato powder (Grabowski *et al.*., 2008). When spray dried sweet potato powder was subjected to a temperature ramp under a shear rate of 10/ s, it was found that the viscosity of the suspension decreased As the temperature was increased from 25 to 55 °C, the apparent viscosity increased from 0.042 to 0.070 Pa s as temperature was ramped from 25 to 95 °C, and then increased upon cooling from 95 to 25 °C. Rheologically, the reconstituted sweet potato slurries behaved similarly to pre-gelatinized starch solutions. Thus, spray dried sweet potato powders have a potential to enhance food systems as a thickener with natural colors.

Studies on steady and dynamic shear rheological properties of the hot-air dried sweet potato flour dispersions indicated that sweet potato flour slurries at 25 °C showed a shear-thinning fluid exhibiting a yield stress. The magnitudes of Casson yield stress, consistency index and apparent viscosity increased with an increase in concentration. Within the temperature range of 25-70 °C, the apparent viscosity obeyed the Arrhenius temperature relationship with high determination coefficient with activation energies ranging 0.015-0.024 KJ/mol. Both power law and exponential type models were used to establish the relationship between concentration and apparent viscosity. Magnitudes of G ' and G " increased with an increase in flour concentration. G ' values were higher than G " over the most of the frequency range, and both parameters were frequency dependent (Chun and Yoo, 2006). The porridge made from blends containing fermented sweet potato was about seven times less viscous than the porridge from the traditional sorghum complementary food (Nnam, 2001). Shih *et al.* (2006) investigated the rheological properties of rice-sweet potato flour mixes as a 100% substitute of wheat flour in gluten-free pan cake. In contrast to the porridge blends reported by Nnam (2001), addition of sweet potato flour (10-40%) enhanced the hydration capacity of the rice batter and resulted in increased batter viscosity, and was comparable with that of the traditional wheat batters.

Paste Viscosities: Native sweet potato flour showed unrestricted swelling, exhibiting maximum viscosity at a relatively shorter period of heating. In contrast, the suspensions of the heat processed flour showed reduced viscosity indices (Figure 7). Reheating the slurries of pre-gelatinized materials caused a decrease in paste viscosity leading to 'thinning' of the slurry. The hot air-dried flour paste showed relatively low viscosity compared to drum dried material, though the severity of heat treatment was more in the latter (Avula *et al.*, 2006). The temperature during hot air drying was more conducive for amylolytic hydrolysis by endogenous amylases and hence the breakdown of starch led to lower viscosity. Set back viscosity of drum dried and hot air dried flours has notably decreased, compared to native flour, validating thermal and enzymatic degradation of starch. A low set back value indicates a non-cohesive paste, which has many industrial implications. Reduction in viscosity is particularly important in the preparation of weaning and supplementary foods from starchy raw materials (Muyonga *et al.,* 2001).

Acetylated flour showed least paste viscosity showing restricted swelling of starch granules, due to the presence of substituent functional groups. The viscosity values obtained after isothermal holding at 95 °C (hot paste viscosity, HPV) were much lower than peak viscosity (PV) values (Avula *et al.*, 2007b). The tendency toward setback or gel formation was minimized in acetylated flour due to the presence of functional groups that prevent starch chains from association (Moorthy, 2002). The degree of substitution (DS) for a starch derivative is defined as the number of hydroxyl groups substituted per D-glucopyranosyl structural unit of the starch polymer. Since each D-glucose unit possesses three reactive hydroxyl groups, the maximum possible DS value is 3. Therefore, the reactions to form acetylated starches can be controlled with high accuracy by adjusting the molar ratio of the reagent and catalyst in the reaction mixture, in order to obtain the desired DS value (Wang and Wang, 2001).

The high pasting profile of the enzyme modified flour shows that the starch molecules were strengthened as a result of modification and resisted breakdown of paste. The formation of enzyme-starch complex would have imparted rigidity to enzyme modified flour resulting in higher pasting viscosities. The peak viscosity of fermented flour was greater than that of unfermented flour (Adeyami and Beckley, 1986). Leman *et al.* (2005) observed an increase in cold paste viscosity (CPV) of starch treated with maltogenic amylase.

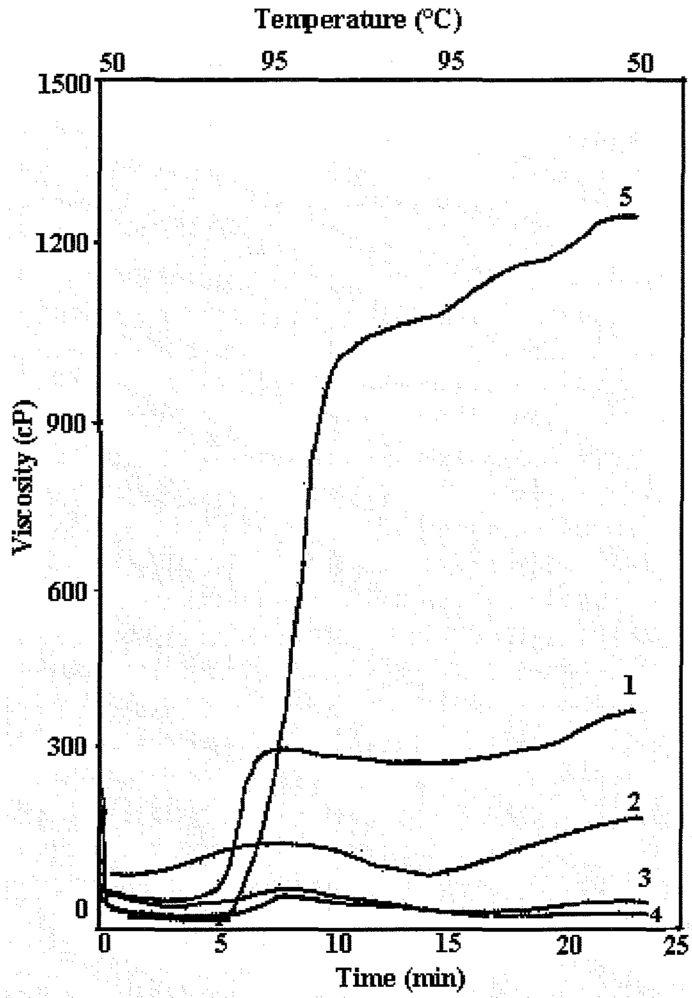

Figure 7. Viscoamylograms of sweet potato flours. 1. Native, 2. Drum dried, 3. Hot air dried, 4. Acetylated, 5. Enzyme modified (adapted from Avula et al., 2007b; Avula unpublished data).

The thermal and mechanical stability and low retrogradation pattern shown by enzyme modified flours are important characteristics useful for baked and frozen products. High paste viscosities are desirable in flours used as thickeners (Weissenborn *et al.*, 1994), whereas low peak viscosities are desirable for high-calorie food formulations such as weaning and specialty foods. The setback (CPV-HPV) or retrogradation value was lower in acetylated flour compared to enzyme modified flour. A higher set back value is useful in products that require a high viscosity and paste stability at low temperature (Oduro *et al.*, 2000). Use of enzyme modified flour is recommended for manufacture of low-fat-low sugar wafers and other bakery products. Enzyme modified flour showed an improvement in the emulsifying and oil absorption capacity (Taeuful *et al.*, 1992).

Pasting properties of the white-fleshed sweet potato cultivar exhibited lower tendency for retrogradation (Osundahunsi *et al.*, 2003). Addition of sweet potato flour and fiber fractions to white wheat flour reduced the pasting properties of the resulting gels by up to seven-folds compared with the wheat flour gel (Mais and Brennan, 2008). The low mean peak viscosity of different genotypes was explained by the endogenous amylase activity in sweet potato flour. Indeed sweet potato flours with inhibited amylase activity by using $AgNO_3$ showed much higher peak viscosity (Collado and Corke, 1999). Varieties, amylase concentration and flour particle size are all crucial factors determining the density and viscosity of the pastes (Iwuoha and Nwakanma, 1998).

Thermal properties: Thermal properties of modified sweet potato flours, measured by DSC, differed significantly. Endotherm peaks of native flour and its enthalpy appeared between 68 – 78.5°C. The transition temperatures (T_o, T_p and T_c), and enthalpy (ΔH) of different flours are summarized in Table 5. Higher gelatinization enthalpy of native flour was due to the more stable granular structure and greater crystallinity (Ganga and Corke, 1999). The differences in transition temperatures may be attributed to the differences in granular structure, amylose content and gelatinization temperature between the starches (Moorthy, 2002).

A typical DSC (Differential Scanning Colorimeter) endotherm was observed for gelatinization of native flour. However, drum-dried and hot-air dried flours did not show any gelatinization endotherm when heated up to 100°C, which confirmed the changed nature of starch granules as a result of processing. Gelatinization enthalpy depends on a number of factors such as crystallinity and intermolecular bonding. Biladeris (1990) and Leszkowiat *et al.* (1990) have suggested that higher transition temperatures indicate more stable amorphous regions and lower degree of chain branching. Acetylated flour showed reduced gelatinization temperature and ΔH, compared to native flour (Table 5). Gelatinization temperature of enzyme modified flour has not changed much but the ΔH increased as a result of enzyme treatment. The DSC curve indicates that the behavior of conjugate of starch and enzyme is almost same as that of native flour excepting for a slight difference in peak and conclusion temperatures. The crystallinity of starch granules in enzyme modified flour was comparable with that of native granule even after enzyme modification. The increase in heat energy in enzyme modified flour indicates that the granules are bound by protein (enzyme-starch complex), that resulted in stronger association of the molecules (Avula *et al.*, 2007b). Using a viscograph, Iwe and Onuh (1992) reported a pasting temperature of 79°C when the degree of starch gelatinization of sweet potato flour was 50%. The electrical conductivity of flour/starch suspensions was found to increase upon gelatinization because of the release of ions from starch granules. Hence, the electrical conductivity measurement could be used as an on-line technique to monitor the whole process of starch gelatinization (Chaiwanichsiri *et al.*, 2001).

Table 5. DSC Characteristics of sweet potato flours

Sweet potato flour	T_0	T_p	T_c	ΔH J/g
Native	68.0	71.8	78.5	10.6
Acetylated	55.9	63.2	67.3	1.7
Enzyme Modified	73.5	76.9	86.9	11.4

Source: Avula et al., 2007b.

Cooked sweet potatoes contain more than 22% sugar on a dry weight basis (Truong *et al.*, 1986). Food products containing substances with low molecular weights, such as sugars, have very low glass transition temperatures (T_g), so these components can depress the T_g of the entire system. If the temperature of the spray-dried particle is greater than 20 °C above the glass transition temperature of that product, the particle will exhibit sticky behavior (Bhandari and Howes, 1999). The glass transition temperature of sweet potato powder increased with the addition of maltodextrin (Figure 8). Conversely, the glass transition temperature of the powders was reduced as the amount of alpha-amylase allowed to act on the puree was increased (Grabowski *et al.*, 2006). This reduction was expected as the amylase breaks down starch into lower molecular weight dextrins. Additionally, the amylase-treated powders also had higher moisture content, and, thus, the additional water could lower the glass transition temperature (Grabowski *et al.*, 2008).

Solubility and Water Absorption: The instant properties of a powder involve its ability to dissolve in water. Since most powdered foods are intended for rehydration, the ideal powder would wet quickly and thoroughly, sink rather than float, and disperse / dissolve without lumps (Hogekamp and Schubert, 2003). The solubility index of spray dried sweet potato powder increased and its water-holding capacity reduced. The water solubility index of the powder increased with increase in the amount of maltodextrin addition. Maltodextrin can form outer layers on the drops and alter the surface stickiness of particles due to the transformation into glassy state (Grabowski *et al.*, 2006). The changes in surface stickiness reduce particle-particle cohesion and particle-wall adhesion during spray drying, resulting in less agglomerate formation and, therefore, lower water-holding capacity of the powders. Drum dried flour showed higher solubility values whereas the acetylated and enzyme modified flours showed the least values, though all the flours showed increasing values with increase in temperature (Figure 9). The increase in solubility was highest at 96°C for drum dried flour followed by hot air dried flour. The pre-gelatinized starch is expected to exhibit high solubility in cold water than unmodified starch (Morrison, 1988).

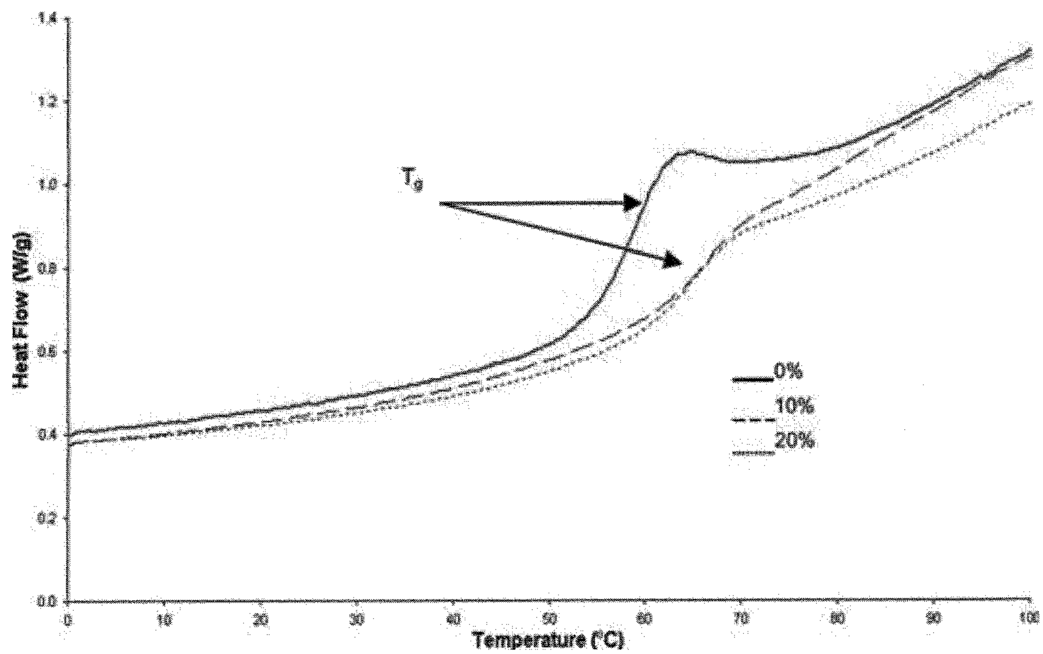

Figure 8. DSC Thermograms showing showing glass transition temperature with increased levels of maltodextrin (adapted from Grabowski et al. 2006).

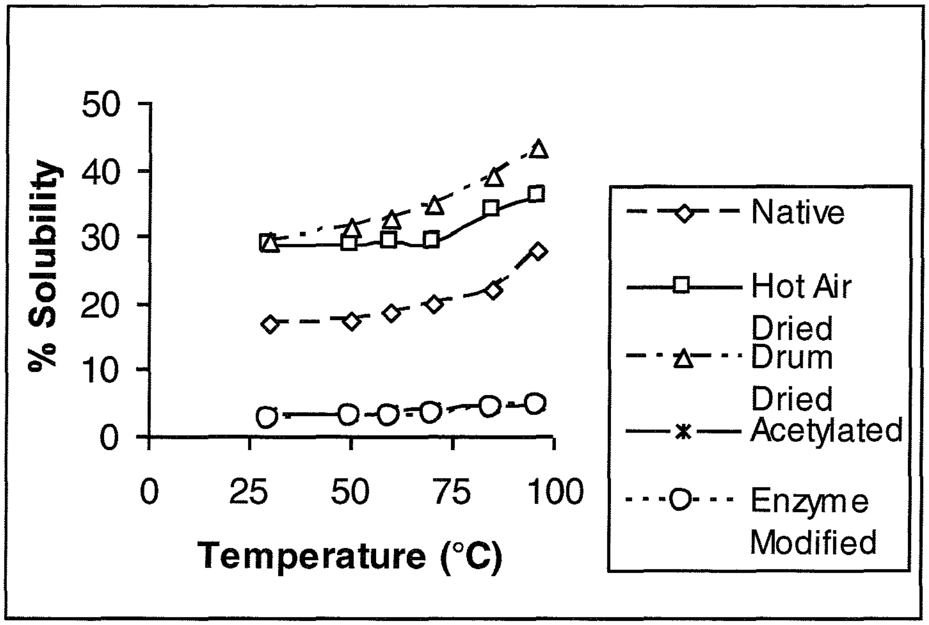

Figure 9. Solubility of sweet potato flours at different temperatures (adapted from Avula *et al.*, 2006, 2007a).

The anamolies, if any, are probably due to starch retrogradation and extent of partial disintegration during milling (Kaur *et al.*, 2002). The solubility of acetylated flour, though slightly increased with temperature, was found to be lower than that of native flour (Figure 9). The substituent groups made the associative bonds stronger in addition to presumably the formation of amylose - lipid complexes. Thus drum dried flour with better solubility even at low temperatures becomes an ideal choice for product formulations (Avula *et al.*, 2006).

Drum dried flour exhibited higher swelling power than hot air- dried, acetylated and enzyme modified flours at 30°C - 96°C. The increase in swelling and solubility values of differently treated sweet potato flours, therefore, can be attributed to a greater degree of macromolecular disorganization and also to variations in the degradation of starch during thermal treatments (Tan and Chinnaswamy, 1993).

Factors like amylose - amylopectin ratio, chain length and molecular weight distribution, degree / length of branching and conformation determine the degree of swelling and solubility (Rickard *et al.*, 1991). High amylose content and presence of stronger or a higher number of intermolecular bonds can reduce swelling (Delpeuch, 1965). Formation of lipid-starch complex can also offer low swelling volume (Swinkles, 1985) as also the presence of non-starch carbohydrates and other constituents in the starch (Eliasson and Gudmundsson, 1996; Leach *et al.*, 1959).

Enzyme modified flours showed reduced swelling power compared to native flour (Avula *et al.*, 2007a). Thus, highly associated starch granules with an extensive and strongly bonded micellar structures display relatively great resistance towards swelling (Mariam *et al.*, 1996). The presence of protein (enzyme-starch complex), imparts rigidity and contributes to the limited leaching of starch (Colonna *et al.*, 1979). The starchy flour extracted from fermented tubers also exhibited the same trend (Moorthy *et al.*, 1993). Absorption properties of extruded sweet potato flour are considered to be fairly good and quite stable (Iwe and Onuh, 1992).

The swelling volume of the sweet potato flour from different genotypes in distilled water had a mean of 15.7 ml/g, ranging from 11.8 ml/g to 18.8 ml/g (Collado and Corke, 1999). The difference in morphological structure of granules may also be responsible for the differences in swelling power and solubility (Adebowale *et al.*, 2002).

Sediment volume of processed starchy products is an index of starch gelatinization, and thus it provides a clear distinction between various precooked products. Drum dried flour exhibited higher sediment volume than enzyme modified and acetylated flours (Table 6), indicating a high degree of gelatinization in drum dried flour, followed by hot air dried flour (Avula *et al.*, 2007b). The consistency of a cold flour paste in 0.2 N KOH is inversely correlated with viscoamylograph cold paste viscosity. Gel mobility is related to the degree of starch gelatinization, unaffected by starch reassociation, and hence could be a good test for the extent of gelatinization (Unnikrishnan and Bhattacharya, 1988). Drum dried flour showed significantly higher gel consistency followed by hot air dried flour compared to enzyme modified and acetylated flours (Table 6). The values of gel consistency of sweet potato flours were correlated with their swelling and solubility patterns. Excepting acetylated flour, all other treated flours were also correlated with their cold paste viscosities (Avula *et al.*, 2007a; Avula, unpublished data).

Table 6. Sediment Volume and Gel Consistency of sweet potato flours

Flour	Sediment Volume (ml)	Gel Consistency (mm)
Native	10.0	40.0
Drum dried	37.4	274.0
Hot air dried	16.6	156.0
Acetylated	9.0	25.0
Enzyme Modified	9.0	20.0

Source: Avula *et al.* (2006; 2007b).

PRODUCT APPLICATIONS

Many studies have reported the feasibility of using sweet potato flour as an alternative to wheat, especially in bakery products (Singh *et al.*, 2008). Commercial bakeries in Peru produced widely accepted bread supplemented with up to 30% sweet potato (Huaman, 1992; Palomar *et al.*, 1981). Substitution levels as high as 65% sweet potato flour has resulted in bread with acceptable loaf volumes, flavor and texture as that of bread made of wheat flour (Greene *et al.*, 2003; Green and Bovell-Benjamin, 2004).

Bovell-Benjamin (2007) reviewed the potential utilization of sweet potato in the Ugandan and Kenyan Food systems. Nungo *et al.* (2000) evaluated the feasibility of several products that included *mashenye*, *mandazi*, and *chapathi* , which were selected as marketable products. In Mali, West Africa, the dehydrated sweet potatoes are usually rehydrated and added to sauce with other condiments and eaten with a stiff cereal porridge or rice (Scheuring *et al.*, 1996). Sweet potato is processed into two local products called *Michembe* (the roots are withered, cut into slices, and dried) and *Matobolwa* (dried product made from boiled and sliced roots) in Tanzania. These products can have a shelf-life of 5-8 months. Other products that have been prepared in Tanzania include cakes, *chapathis*, donuts, *kaimati*, and buns

(Gichuki *et al.*, 2005). Other potential sweet potato products include bread, buns, noodles, pancake mixes, chips (Bovell-Benjamin, 2007; Salmah and Zaidah, 2005). The utilization of sweet potato as a main ingredient in making delicious cakes or local desserts is quite popular in Malaysia, and more than 32 sweet potatoes based traditional cakes and desserts are available in the Malaysian market (Zainun and Zahara, 2005). A ready to use flour mix using sweet potato flour to prepare *Kuih Kacau Keldek* was also developed and found acceptable. An extensive sweet potato recipe list including dishes from China, Ghana, Guyana, India, Japan, and the United States is documented by Hill *et al.* (1992).

In the case of flat bread with less volume (*chapathis*, *poories*, buns), high levels of wheat flour substitution have been used successfully (Greene *et al.* 2003, Hagenimana *et al.*, 1999a; Green and Bovell-Benjamin, 2004). For the salted western type of bread, sweet potato flour has been found to have a negative effect on loaf volume, flavor, color, and texture (Amano. 1996; Greene *et al.*, 2003; Roa *et al.,* 1996). Bread containing 50% sweet potato flour with high-gluten dough enhancers had the highest loaf volumes Hathorn *et al.* (2008). Golden bread made from fresh roots of medium-intensity orange-fleshed sweet potato varieties is a good source of ß-carotene and is economically viable when the price ratio of wheat flour to raw orange-fleshed sweet potato root is at least 1.5 (Low and van Jaarsveld, 2008).

Extruded ready-to-eat breakfast cereal containing 75-100% sweet potato flour are promising products to be included in human diets (Dansby and Bovell-Benjamin, 2003a; 2003b). Fonseca *et al.* (2008) and Zhang (1998) reported optimal extrusion conditions for β-carotene retention in extruded sweet potato flour and sweet potato / peanut blends. Sweet potato flour from *Jalomas* and *Telong* varieties have good potential as raw material for the production of extruded snack food and RTE(ready- to- eat) breakfast food (Lee, 2005). The single screw extruder was used in these studies, and the effect of screw speed, feeder flow rate and moisture content on the extrudate quality were investigated in these studies. The severe heat treatment received by sweet potato extrudates rendered them applicable in soup bases, flour mixes and breakfast foods (Iwe, 2000; Iwe *et al.*, 2001a, b, c; Iwe and Ngoddy, 1998). Gluten-free pan-cakes, mandazis and other processed products showed increase in β-carotene content on incorporation of sweet potato flour (Hagenimana *et al.*, 1999b; Hathorne *et al.*, 2008; Limmongreungrat and Huang, 2007; Oyunga-Obugi *et al.*, 2005; Shih *et al.*, 2006).

Conversion of drum dried sweet potato flour to ethanol was studied by Reddy and Basappa (1997). A wine like product containing ethanol up to 8.6% (w/v), with desirable aroma and color was developed by treating drum dried flour with pectinase, and culture filtrate (α-amylase and glucoamylase) of *Endomycopsis fibuligera*. The inoculated flour was fermented for 3 days.

Lactobacillus plantarum MTCC 1407 was used for direct fermentation of sweet potato flour to lactic acid under semi- solid fermentation (Panda and Ray, 2008). Pasta made from alkaline-treated sweet potato flour had the lowest cooking loss with the highest firmness. Cooking losses increased as levels of sweet potato flour decreased (Limmongreungrat and Huang, 2007).

The color parameters were highly correlated with the color of dough sheets for white-salted and yellow-alkaline noodles made from wheat and sweet potato composite flour (Collado *et al.*, 1997; Oyunga-Obugi *et al.* 2005). Vegetarian products such as pan cakes and tortillas, made with sweet potato were developed for use in nutritious meals for future space explorers. Because of their consumer acceptability, these products were recommended to

National Aeronautics and Space Administration (NASA)'s Advanced Life Support Program for inclusion in a vegetarian menu plan designed for Lunar / Mars space missions (Wilson *et al.*, 1998). Sweet potato flour has also been incorporated in cocoa drink, rice-based beverage and instant weaning food (Espinola *et al.*, 1998; Suh *et al.*, 2003; Truong, 1992).

CONCLUSION

Sweet potato purees and powders can be used as thickening and gelling agents to impart desired textural properties, and enhance the nutritional values, antioxidant activity as well as natural color (e.g. orange and purple) of numerous food products. Furthermore, these ingredients from sweet potatoes can be used as alternatives to wheat products for individuals diagnosed with celiac disease and incorporated in low glycemic index foods for diabetics. Processing technologies for producing sweet potato purees and powders at small and large scale operations have been developed in different countries. For purees, the new development in aseptic processing using continuous flow microwave heating provides a great opportunity for the sweet potato industry in delivering the nutrient-rich and shelf-stable purees to food processors, institutional food services as well as emergency food relieve organizations around the world. With regard to the dehydrated forms, selection of sweet potato cultivars with high levels of dry matter and phytonutrients should go hand in hand and by adopting technological improvements to reduce processing cost. Aiming at specific functionality, nutrient retention and product storability need to be considered in order to provide competitiveness of these ingredients in the food processing sectors. With growing demand for convenient and healthy foods, sweet potato purees and dehydrated forms have good potential to be used as functional ingredients in processed foods.

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